RM-78-41

HEALTH AND ECONOMIC DEVELOPMENT I: INFANT MORTALITY

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August 1978

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Research Memoranda are interim reports on research being conducted by the International Institute for Applied Systems Analysis, and as such receive only limited scientific review. Views or opinions contained herein do not necessarily represent those of the Institute or of the National Member Organizations supporting the Institute.

This work has been supported in part by the United Nations Environmental Programme (UNEP); however, UNEP bears no responsibility for the form or substance of the study.

PREFACE

This report is one in a series by the authors describing their work on the relationship between health and energy. The study was carried out at IIASA in 1976 to 1977 as part of the joint UNEP/IIASA project, *The Comparison of Energy Options: A Methodological Study*. Using cross-sectional as well as longitudinal data, the series examines the role of economic development in improving health. The national data used here extended over the period 1900 to 1975 and covered 99 percent of the world population. The results of this research are descriptive, but may be used in a predictive manner for energy, education, and health policy decisions.

This report studies the relationship between infant mortality on the one hand and nutritional, medical care, social, and economic indicators on the other.

SUMMARY

In a previous report (*Energy Consumption as an Indicator of Longevity*, PP-78-6), we described the relationship between energy consumption and health. In this follow-up study, we examine certain independent variables in order to ascertain the mechanisms underlying the effect of development on infant mortality. Those variables include: nutrition, medical care, education, religion, urbanization, and GNP. The study population consists of all nations for which data were available. Statistical analysis is both cross-sectional and longitudinal. We conclude from this analysis that economic development is responsible for approximately half of the reduction in infant mortality that has occurred over the past few decades, and that, of the intervening variables tested, energy consumption and literacy bear a strong and predictive relationship to declining infant death rates. In addition, other still unidentified factors are operating to reduce death rates throughout the world.

Health and Economic Development I: Infant Mortality

INTRODUCTION

Although there is much in demography that is controversial, there is little dispute regarding an inverse relationship between economic development and infant mortality. Demographers generally consider the major intervening factors to be increased access to food, and improved medical care, sanitation, and housing. The relative contribution of each of these and other factors has been difficult to quantify, partly because the independent variables are so highly intercorrelated and partly because valid measures of economic development, particularly in international comparisons, are not easily achieved. For these reasons the precise nature of the relationship between economic development and infant mortality remains enigmatic. In this paper we attempt an analysis of certain variables related to economic development as they may affect infant mortality.

Quantification of the relationship between economic development and infant mortality is not merely a matter of academic scholarship. Few issues create more public concern than population growth on the one hand and poverty on the other. Light might be shed on both of these phenomena if their interrelationships were clarified. Because economic development clearly has a powerful influence on population parameters, increased knowledge of interactions among these variables can contribute to the development of population models. As it is, projections of population growth generally rest on extrapolations from past trends rather than on any predictive model incorporating economic factors [1].

Not all age groups have benefited equally from the declining mortality rates of the past several decades. Infant death rates have shown the greatest reductions, and we have chosen to focus on that age group in this study. A more general measure of health is longevity from birth, which combines death rates at all age groups. We study longevity separately in a sequel paper [2].

Elsewhere, we have identified two factors operating to reduce infant mortality: one is closely related to and dependent upon economic development and the other is a secular trend unrelated to economic development [3]. These relationships are shown in Figure 1. Specifically, the question to which we address ourselves is whether we can offer some explanation of either of these phenomena with currently available data.

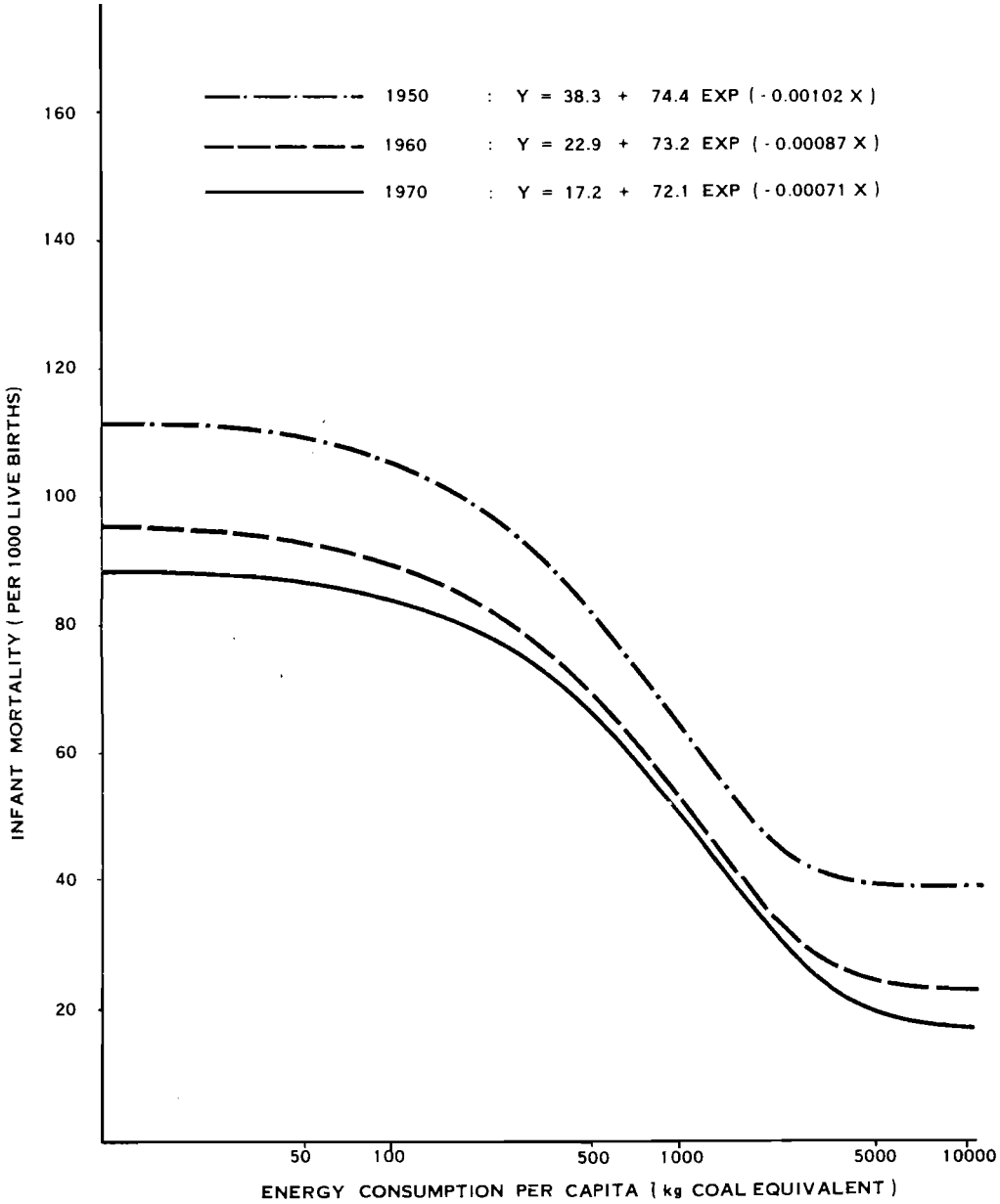

Figure 1. Relationship between energy consumption and infant mortality for 47 countries (1950-1960-1970 data) from [3].

We have carried out both cross-sectional and longitudinal studies on 150 countries which contain more than 99 percent of the world's population. It was not our intent to carry out a detailed clinicopathologic study of infant mortality, but rather to examine those gross variables for which data are now generally available for most countries to test whether equations could be derived which would permit linking infant mortality to economic development.

The variables examined, the shorthand notations used in text and tables and their sources are as follow:

INFMORT	= infant mortality per 1000 live births [4]
LONGBI	= longevity from birth in years [4]
FERTILITY	= annual births per woman aged 15 to 45, calculated from statistics available in [4]
BIRTH RT	= live births per 1000 population [4]
DEATH RT	= deaths per 1000 population [4]
GNP	= per capita GNP in dollars [5]
ENERGY	= per capita annual commercial energy consumption in kilograms of coal equivalent (kgce) [6]
% LABAG	= percent of labor force employed in agriculture [7]
% GTH	= percent of total population living in cities of more than 100,000, calculated from statistics in [8]
% LITERACY	= percent of persons over age 15 able to read and write [9,10]
ENROLM	= percent of eligible population enrolled in school [7]
TOTCALS	= per capita total daily calories [11]
CARBCALS	= per capita daily calories from carbohydrate [11]
FATCALS	= per capita daily calories from fat [11]
PROTCALS	= per capita daily calories from animal and vegetable protein [11]
APRCALS	= per capita daily calories from animal protein [11]
POP/MD	= number of persons per physician [8]
POP/BED	= number of persons per hospital bed [8]
GINI	= an index of distribution of income [7]
% HALF	= smallest percent of population receiving half of total income [7]
% CHRISTIAN	= percent of population who are Christian [7]
% MOSLEM	= percent of population who are Moslem [7].

Infant mortality data used are those reported by each country. By definition, infant mortality refers to all deaths during the first year per 1000 live births. Difficulties with the data are twofold: incomplete reporting by local authorities and variations in the definition of live birth. The latter problem has been addressed by combining stillbirths with early postnatal deaths into a separate category, perinatal mortality. Such data are available for only a small number of cases. Underreporting undoubtedly occurs, particularly in rural areas of less developed countries. Unfortunately the magnitude of this bias cannot accurately be estimated, but would operate to underestimate infant mortality. We also cannot exclude the possibility that some countries purposefully underestimate or overestimate infant mortality rates for political purposes. We overcome this difficulty to some extent by the use of longitudinal data where it is assumed that reporting practices within countries are fairly constant.

As a measure of economic development, we have chosen to use annual per capita commercial energy consumption. Such an index has certain advantages and disadvantages. Energy consumption alone is not identical with economic development, as is illustrated by some of the small developing OPEC countries which have

enormous levels of energy consumption; but it is a necessary component of the process of development. However, the quantitative relationships are as yet unclear, and various pathways to development may have different energy requirements, as noted in the differing energy consumption levels of nations with similar degrees of development [12].

The advantage of energy consumption as a measure of economic development is that it provides a constant physical unit, comparable over time and among countries. Per capita GNP is often used as a measure of economic development. This quantity suffers from the defect of requiring arbitrary adjustments when used among nations with different currencies or for longitudinal studies where adjustments for inflation or deflation are necessary. There are other defects inherent in the use of GNP as a measure of economic activity that need not be discussed here but have been reviewed elsewhere [13].

We have described elsewhere the regression of infant mortality on energy consumption for the years 1950, 1960, and 1970, using a logistic curve of the form $y = \alpha + be^{cx}$ presented in Figure 1 [3]. We interpreted the data as demonstrating distinct phases in economic development as it affects mortality, namely from 0 to 99 kgce (Phase I), 100 to 1999 kgce (Phase II), 2000 to 3999 kgce (Phase III), and more than 4000 kgce (Phase IV). Infant mortality is relatively insensitive to increasing energy consumption throughout the first and fourth phases, but declines sharply in the middle two phases, i.e. from 100 to 4000 kgce. In this paper we further divide Phase II into two categories so as to examine the "take-off" phase of economic development in more detail: Phase IIa from 100 to 399 kgce, and IIb from 400 to 1999 kgce.

The 29 countries in Phase I, containing 9 percent of the world's population, are characterized by illiteracy, inadequate, monotonous and uncertain diet, and high rates of infant mortality and fertility. The primary economic activity is subsistence farming. There is little use of money and energy inputs are largely from human muscle. Ethiopia, Nepal, and much of Africa below the Sahara are examples.

Phases IIa and IIb, the early phases of economic development, contain 62 percent of the world's population. Per capita GNP has begun to rise. The portion of the labor force engaged in agriculture begins to fall. Urbanization commences. Infant mortality starts to fall and longevity increases by approximately 10 years in each of these phases. India, China, and much of Latin America are examples. In Phase III all of these trends continue, although only small gains in longevity occur. In Phase IV the development process is mature; literacy is now virtually universal, and health benefits begin to plateau in spite of progressive industrialization.

DATA ANALYSIS

We obtained current (1975) values of the above-mentioned variables, whenever possible, for 150 countries. While information on population and vital statistics was available for each country, other data were incomplete. For instance, GINI and % HALF were available for only 71 countries. However, 116 countries had complete data on the variables used in most of the analysis.

Results based on these data constitute our cross-sectional analysis. Statistical averages (weighted by population) were obtained using complete data on each variable. These averages are presented in Table 1 by energy phase. Standardized scores, i.e. (phase mean - grand mean)/total standard deviation, are shown in Figure 2. The signs of these scores were adjusted so that they were all positive for the developed phases.

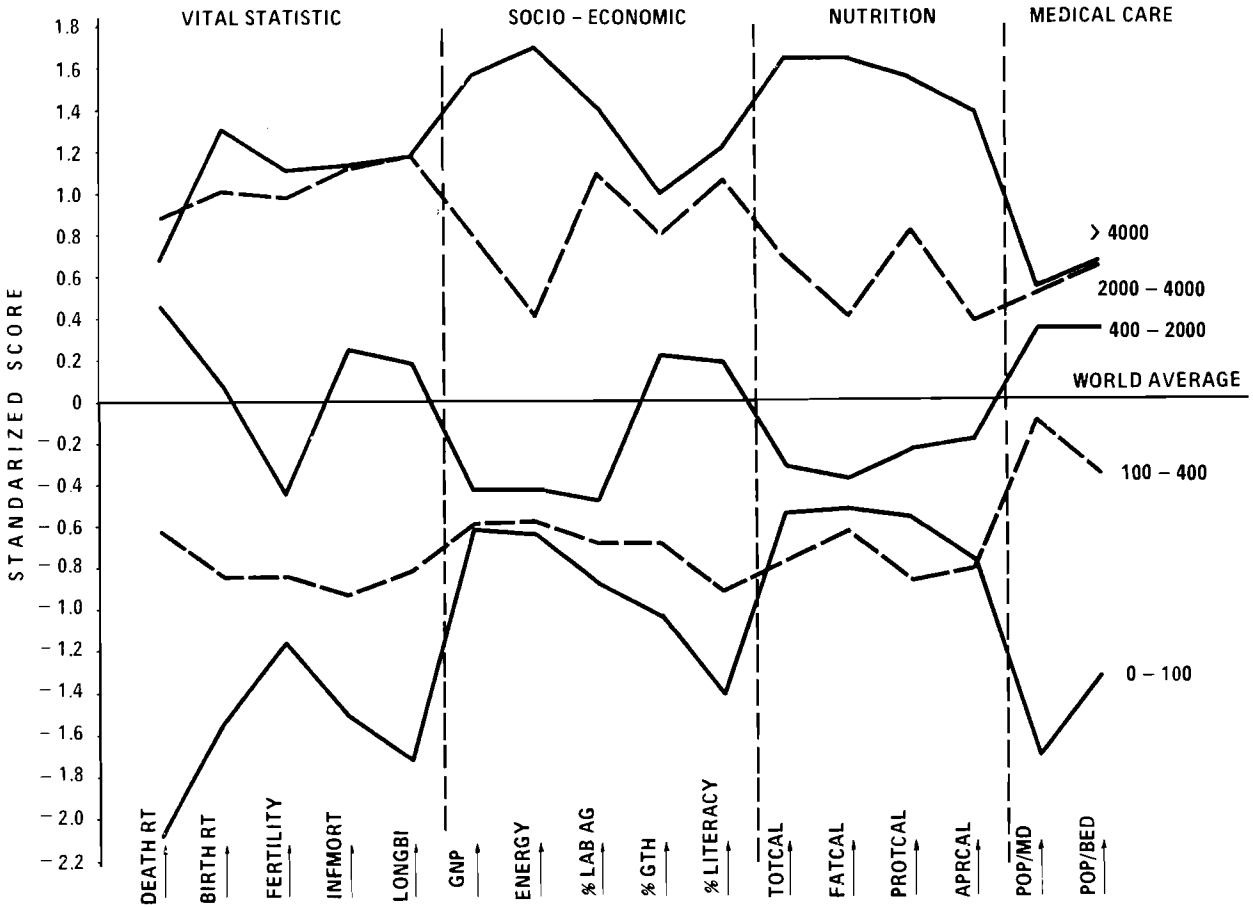

Figure 2. Standardized scores for 16 variables, by annual per capita energy consumption (kgce), 150 countries.

Table 1. Means of selected variables, by development phase (1975 data)

Variables	I <100 kgce (N=29)	IIa 100-400 kgce (N=34)	IIb 400-1000 kgce (N=41)	III 2000-4000 kgce (N=16)	IV >4000 kgce (N=21)	Total (N=150)
TOTAL POPULATION*	365	1113	1337	296	798	3954
DEATH RATE	23.0	15.8	10.5	8.5	9.4	12.76
BIRTH RATE	47.4	41.5	30.9	20.0	16.5	31.7
FERTILITY	222	202	176	85	77	148
INFMORT	158.6	128.6	67.0	21.0	20.8	80.0
LONGBI	41.3	50.6	60.9	71.0	71.0	59.0
GNP	120	160	459	2615	3967	1219
ENERGY	51.0	201	700	3277	7209	2022
% LABAG	72.3	68.2	63.7	28.3	21.0	52.6
% GTH	6.7	13.3	30.3	41.5	45.3	26.4
% LITERACY	21.2	36.0	68.2	93.7	98.4	62.9
TOTCALS	2092	1979	2201	2673	3131	2354
CARBCALS	1686	1545	1665	1691	1668	1636
FATCALS	295	257	350	619	1043	480
PROTCALS	220	200	243	314	364	259
APRCALS	36	31	77	123	202	93
POP/MD	28234	8355	2812	745	564	7067
POP/BED	2838	1496	540	121	106	1004

*in millions

Weighted simple correlations were estimated from complete pairs of correlations. Weighted multiple regression analysis of INFMORT on various explanatory variables was based on the 116 countries with complete data. This analysis excluded % LABAG, ENROLM, GINI and % HALF, as described later. The longitudinal analysis is based on a subsample of 44 countries for which information was available in 1950 and 1970.

In the regression and correlation analysis some variables were transformed to their logarithmic values since this improved linear correlation with INFMORT. Variables so transformed were GNP, ENERGY, POP/MD, and POP/BED. Finally, to further illustrate the degree of linear dependence between INFMORT and the explanatory variables, we chose to report the proportion of standard deviation (SD) explained, rather than the familiar proportion of variance, since the SD is in the same units as the original measurements. While the proportion of variance explained is the square of the multiple correlation coefficient (r^2), the proportion of SD is $1 - \sqrt{1 - r^2}$ [14]. The latter is always less than or equal to the former. For example, if $r = 0.8$, then the proportion of variance explained is 0.64 (64 percent) while the proportion of SD explained is 0.40 (40 percent).

CROSS-SECTIONAL ANALYSIS

In the following sections, we shall analyze each set of explanatory variables separately.

Nutrition

The relationship between national average food consumption data and nutrition of the fetal host-mother and the postnatal infant is uncertain and probably of less importance than traditional attitudes towards maternal and infant feeding practices. Under these circumstances, aggregated food data provide information only on the general nutritional background to infant mortality effects. Our nutritional variables are total daily calories as well as major nutritional components, i.e., carbohydrate, fat, and protein of both plant and animal origin (Figure 3 and Table 1). Since nutrition increases in a nonlinear fashion with energy consumption, the curves in Figure 3 represent least-squares quadratic regression equations of the nutritional variables on the logarithm of energy consumption.

Average caloric intake per capita throughout the world is 2421, rising from 2115 in the Phase I group to 2993 in Phase IV. Carbohydrate calories remain fairly constant with increasing wealth and access to greater quantity and variety of foodstuffs. Additional calories come from increasing fat and protein. Fat provides 14 percent of diets in the poorest countries, coming mostly from non-separated vegetable fats, and 36 percent in developed countries, with separated fats and animal fats as the predominant source. Protein content remains fairly constant at

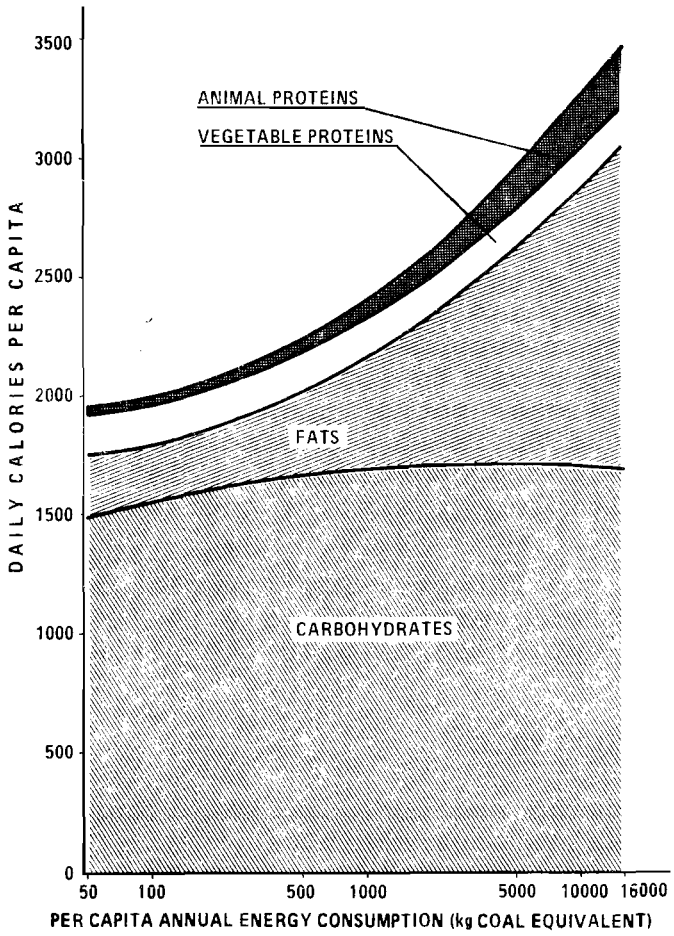

Figure 3. Average daily availability of calories from major food groups, by national energy consumption.

all caloric levels (almost 11 percent) but there is a gradual shift from vegetable to animal sources. In Phase I, 17 percent of protein calories comes from animal sources, in contrast to 57 percent in Phase IV. It is likely that these mean values conceal the economic and temporal maldistribution that occurs with nutrition, particularly in poorer countries. Data on this point are very difficult to obtain.

Table 2 includes correlation coefficients of the nutritional variables with infant mortality. Although all of the variables show significant relationships to infant deaths for the total population, only animal protein calories show a relatively consistent relationship within energy groups as well as the highest total correlation coefficient of all nutritional variables.

In another analysis, we used different sets of independent variables in turn as explanatory variables of infant mortality. After noting the percent of standard deviation of infant mortality explained by a given set, we calculated the partial

Table 2. Correlation coefficients: selected variables with infant mortality, by development phase (1975 data)

Variables	I <100 kgce (N=29)	IIa 100-400 kgce (N=34)	IIb 400-1000 kgce (N=41)	III 2000-4000 kgce (N=16)	IV >4000 kgce (N=21)	Total (N=150)
Vital Statistics						
BIRTH RATE	(.36)*	(.11)	.83	(.40)	.39	.92
FERTILITY	(.43)	(-.03)	.68	.55	(-.09)	.91
DEATH RATE	(.05)	.87	.74	.56	-.53	.86
LONGBI	(-.10)	-.86	-.85	-.92	-.79	-.96
% UNDER 15	(-.10)	-.43	.50	(.48)	(.28)	.86
Nutrition						
TOTCALS	.49	-.27	.24	(.43)	.16	-.67
% CARB	(.15)	(.05)	-.33	(-.21)	.89	.58
FATCALS	.52	-.27	(.16)	(.33)	-.89	-.63
PROTCALS	.55	(.02)	(.08)	(.23)	(.11)	-.70
APRCALS	(-.21)	-.48)	-.38	(.07)	-.79	-.82
Education						
% LITERACY	-.55	-.80	-.83	(-.45)	.33	-.96
ENROLM	-.70	-.49	-.65	(-.31)	-.58	-.75
Medical Care						
POP/MD	.67	(.16)	.63	(-.17)	-.79	.89
POP/BED	(-.20)	.42	(.14)	(.47)	(-.23)	.86
Socio-Economic						
GNP	.47	-.42	-.49	-.71	-.83	-.80
ENERGY	(.17)	-.52	(.02)	-.23	-.50	-.88
GINI	-	-.95	(.03)	.90	(-.16)	.36
% HALF	-	.93	(.07)	-.93	(.20)	-.31
% CHRISTIAN	(.16)	-.48	(.21)	.60	-.75	-.44
% MOSLEM	(.05)	(.00)	(.73)	(.33)	.79	.52
% GTH	(.27)	(-.06)	-.46	-.64	-.54	-.78

*Figures in parentheses are not statistically significant at the 0.5 level.

correlation of infant mortality with each of the remaining independent variables. Table 3 shows the results of this analysis for the total sample of countries and for each energy phase. The table lists the percentages of standard deviation explained as well as each variable with a partial correlation greater than 0.5 in absolute value. For the total sample of 116 countries for which complete data were obtained, nutrition alone explained 52 percent of the standard deviation for infant mortality. After removing the linear effect of nutrition, other variables still retained some significance. Adding literacy to the equation further reduced variance, permitting 74 percent of the total standard deviation to be explained. Partial correlations with medical care remained significant after removal of nutrition but reduced variance less than did literacy. Within energy groups, nutrition provided very little reduction in variance except in Phase IV, where, however, variance of infant mortality is already very small (SD = 4.6).

Medical Care

Two measures of medical care are available for the majority of countries studied: ratios of population to numbers of physicians and to hospital beds. Both have serious defects for the purpose of studying impact of medical care on infant mortality. Physicians and hospitals are not equally available to all members of a national population. Inequities occur because of both geographic and economic barriers and will vary among countries in an unpredictable fashion. Furthermore, physicians and hospitals will vary across countries in the amount and quality of attention they give to maternal and child health. Also, doctors and hospitals are not the only vehicle through which the benefits of medical technology are available. National and international public health services are, in the view of many, a more important mechanism for the delivery of effective medical technology than are clinicians. The measures of medical care available to us are more representative of curative than of preventive medicine.

Correlations of population per physician and per hospital bed with infant mortality are high--r = 0.89 and 0.86, respectively--yet we have reasons for doubting that this relationship is strongly causal at all levels of development. They are:

- There is no consistent correlation within energy consumption groups. Of the 10 correlations, 6 are not significant, and 3 that are significant suggest a positive correlation between numbers of doctors or hospital beds and infant mortality.
- Although density of doctors and hospitals explains 60 percent of overall SD, it explains only 10 and 20 percent of SD in the Phase IIa and IIb groups, respectively. It is at these levels of development that the greatest decline in infant mortality occurs. These observations are consistent with a relatively unimportant role of curative medicine in developing countries where infant mortality is still a major health problem.

Table 3. Percent of standard deviation (SD) of infant mortality explained by selected variables; and variables with partial correlation greater than 0.5 in absolute value (1975 data)

	Energy Level (kgce)					
Variables	I <100 kgce (SD=23.2)	IIa 100-400 kgce (SD=24.2)	IIb 400-2000 kgce (SD=32.7)	III 2000-4000 kgce (SD=11.3)	IV >4000 kgce (SD=4.6)	Total (SD=57.1)
Nutritional (NUTS)	5% LIT* MD	12% LIT	20% LIT	3%	54%	52% LIT MD EN
Medical (MD)	22%	10% LIT	20% LIT	5%	37% NUTS EN GTH	60% LIT
Literacy (LIT)	11% NUTS GNP MD	40% NUTS	62%	3% GNP GTH	4% MD NUTS	72%
Energy (EN)	0% NUTS MD LIT	16% LIT	13% LIT	0% GNP GTH	11% MD NUTS GNP	51% LIT
Urban % (GTH)	0% NUTS MD LIT	0% LIT EN	9% LIT	19%	15% MD NUTS GNP	37% LIT EN MD NUTS

*After removing the effect of nutritional variables, % literacy and medical variables have a partial correlation of >0.5 in absolute value with infant mortality. Other entries in this table are similarly interpreted.

Education

Education has long been recognized as a major component of economic development. Both GNP and energy consumption are highly related to literacy. Construction and operation of facilities and equipment, management of markets, and transportation all require trained people and a large percentage of the population who can, at the very least, read. The role of education in reducing infant mortality may appear less obvious than the variables already described, nutrition and medical care, but it is statistically the most powerful explanatory variable that we have identified.

We selected for study two measures of education, literacy and school enrollment. The former is a statistic collected by each country and generally refers only to persons above age 15. School enrollment is an index used by UNESCO for that part of the population aged 5 to 19 inclusive, who are actually enrolled. We also evaluated as an independent variable the percentage of worldwide scientific articles contributed by each country, but it performed so poorly in explaining infant mortality that it was dropped from further consideration.

Of the two variables, literacy was the more potent in explaining infant mortality. The correlation with infant mortality was the strongest found (-0.96), and was consistent in all phases of development with the exception of Phase IV, where the literacy rate, averaging 97.2 percent, becomes a poor indicator. In those developed countries school enrollment becomes a better indicator and correlates moderately well with infant mortality.

Regression analysis also supported the significant effect of literacy (Table 3). Of all the variables, literacy was the most powerful in explaining infant mortality, reducing the standard deviation by 72 percent. Furthermore, in Phases IIa and IIb, in which infant mortality rapidly declines fom 159 to 21 per 1000, literacy alone explains 40 and 44 percent of the standard deviation, respectively. In addition, partial correlation coefficients of literacy remain highly significant after removing any of the other variables.

Urbanization

One of the most consistent characteristics of economic development is the appearance and growth of cities and the increasing proportion of the population living in such cities. In our data, 26.4 percent of the world's population lives in cities of more than 100,000 population. In the least developed countries, 6.7 percent of the population is in such cities, and in the most developed, 45.3 percent.

We assessed a number of measures of urbanization. The United Nations publishes an index of urbanization calculated individually by each country. We also computed for each country the percent of population living in cities larger than 100,000

(GTH) and larger than one million. Any measure of urbanization will suffer from the difficulty of defining city boundaries, but variability in the UN index is greatest due to the widely differing definitions adopted by each country. Of the three indices, GTH exhibited greater statistical correlation with infant mortality and was therefore used as our measure of urbanization.

As shown in Table 2, the correlation coefficient of urbanization with infant mortality was -0.78, and was significant above 400 kgce. In the regression analysis (Table 3), urbanization explains the smallest portion of any of the major variables examined (37 percent). Within energy groups, GTH never explains as much as 20 percent of SD.

Other Variables

Several variables were examined and found to be of little significance. They were therefore dropped from further analysis. We are unable to determine whether this was due to poor quality of the data or to true lack of correlation with infant mortality. These variables were: religion as measured by percent Christian or Moslem, and two measures of distribution of wealth, the GINI index and the percent of population owning half of the wealth (Table 3). Others not reported in this paper are: two measures of sanitation, percent of homes with flushing toilets and of homes with piped water; a measure of housing density, number of persons per room; and an additional measure of education, dollars spent on education per capita.

The logarithm of per capita GNP exhibited increasingly significant correlation of infant mortality with economic development. After removing the effect of both nutrition and medical care in Phase IV, GNP still retained the power to explain 52 percent of the remaining standard deviation. Percent of GNP due to industry and agriculture was of less significance than percent of labor force engaged in agriculture. All three measures were too insignificant to be included in further analysis.

Two other demographic variables were tested as they related to infant mortality, longevity from birth and fertility. The former shows a high degree of correlation with infant mortality, because infant mortality itself partly determines longevity from birth. In addition, mortality rates tend to rise or fall simultaneously in all age groups.

Fertility declines at each stage of development parallel to declining infant mortality. Although there are undoubtedly strong interactions between these variables, evidence suggests that infant mortality declines prior to reduction in fertility [1,15]. Demographic transition theory posits that it is the perception of declining infant mortality that persuades parents to limit family size. Close inspection of Table 1 supports that theory: the sharp decline in fertility lags behind that in infant mortality. There can be no question that short birth

intervals and prolongation of fertility into middle age, common in highly fertile societies, are associated with high levels of infant mortality. The data, reviewed by Wray [16], demonstrate clearly that reduction in family size, reduced parity, and increasing birth intervals all reduce illness and infant mortality.

LONGITUDINAL ANALYSIS

As seen in Figure 1, there is evidence that worldwide infant mortality rates are falling independently of economic development. Nations at all levels of development have benefited by a decrease in infant mortality of approximately 20 deaths per 1000 live births. We therefore tested whether the independent variables discussed above could explain observed declines in infant mortality. Although complete data for variables are not available for 1950, 44 countries do have sufficient data for longitudinal analysis in both 1950 and 1970, and complete data are available for 22 countries in both years. Mean values are shown in Table 4 both for the larger sample of 44 countries used for literacy and energy comparisons and for the smaller sample of 22 countries used for analysis of nutritional, medical, and urbanization variables. The statistical means for the larger sample of 44 countries have been weighted for the 1950 population. The smaller sample of 22 countries, used for more extensive analysis, has not been weighted, principally because of India where the size of the population and anomalous behavior of many of the variables would have distorted the analysis.

Table 4. Statistical means of selected variables (1950 and 1970 data)

Variables	1950	1970	% Change
INFANT MORTALITY*	111.6	57.8	- 48
% LITERACY*	62.3	76.4	+ 23
Energy	1276	2648	+ 108
TOTCALS	2706	2890	+ 7
FATCALS	333	989	+ 197
APRCALS	144	176	+ 22
CARBCALS	2058	1575	- 23
PROTCALS	315	326	+ 3
POP/MD	1751	1225	- 30
POP/BED	358	226	- 37
% GTH	25	36	+ 44

*Based on 44 countries; otherwise 22.

Correlation coefficients for selected variables and infant mortality are shown in Table 5 both for 1950 and for 1970 data. Correlations for the two years are in general quite similar. Differences in infant mortality (1950 to 1970) were also calculated, and the difference was used as a dependent variable and correlated with differences in certain independent variables as shown in Table 5. Of the variables studied, literacy, energy consumption, and two nutritional variables maintained their explanatory value in longitudinal as well as in cross-sectional analysis.

To evaluate the usefulness of each of these three variables in predicting infant mortality decline, 1950 to 1970, we calculated elasticities associated with each from the 1975 cross-sectional data. Infant mortality is estimated to decrease by one unit for a 13.5 percent increase in total calories, a 0.56 percent increase in literacy, or a 0.034 increase in the logarithm of energy consumption. Applying these estimates to the observed increases in these variables from 1950 to 1970, 47, 47, and 49 percent of the decrease in infant mortality was accounted for, respectively. We thus concluded that any or all of these variables can be used as indices of development. Since literacy and energy had the highest correlations with infant mortality (Table 5) and were based on the most complete data (44 countries), we carried out a multiple regression analysis in which infant mortality difference, 1950 to 1970, became the dependent variable, and infant mortality levels 1950, and energy and literacy for 1950 and subsequent 20-year changes became the independent variables. The resulting equation was as follows:

Table 5. Correlation coefficients: selected variables with infant mortality (1950 and 1970 data)

Variables	Infant Mortality (1950)	Infant Mortality (1970)	Difference (1950,1970)
% LITERACY*	-.96	-.98	+.86
ENERGY*	-.89	-.86	+.83
FATCALS	-.76	-.78	(-.29)†
PROTCALS	-.66	-.70	(+.39)
APRCALS	-.78	-.78	+.53
TOTCALS	-.83	-.77	+.69
POP/BED	+.80	+.92	(.06)
POP/MD	+.72	+.75	(-.33)
% GTH	-.57	-.37	(-.16)

*Based on 44 countries; otherwise 22.
†Figures in parentheses are not statistically significant at the 0.5 level.

$$\begin{aligned}\text{Infant mortality difference between 1950 and 1970} = {} & 9.86 \log (\text{energy ratio } (1970, 1950) \\ & + 0.424 (\text{literacy increase } 1970, 1950) \\ & + 1.436 (\text{literacy increase}) \cdot \log (\text{energy ratio}) \\ & - 3.94 \log (\text{energy } 1950) \\ & + 1.16 \text{ literacy } 1950 \\ & + 0.671 \text{ INFMORT } 1950 \\ & - 107.0.\end{aligned} \quad (1)$$

This equation reduces the SD of infant mortality differences from 43 to 6. It incorporates not only linear effects of changes in literacy and energy but also the effect of their interactions as measured by their product. Using the first three terms in this equation, it is possible to calculate various combinations of literacy and energy changes which could have reduced infant mortality by certain amounts. Figure 4 represents graphs of combinations necessary to reduce INFMORT by 20, 40, and 60 per 1000 live births, respectively. These can be interpreted as the isoquants of the economic production curves.

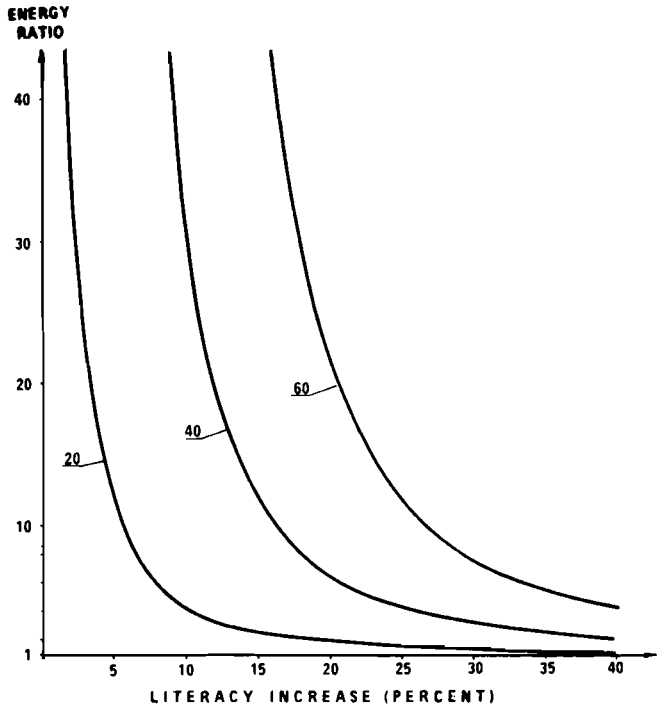

Figure 4. Relationship between increasing energy consumption and literacy increase in producing selected levels of reduction in infant mortality.

The predicted and the actual infant mortality decline for each group of countries by phase of economic development were calculated by use of Equation (1) and are shown in Figure 5. Also shown are the relative contributions to infant mortality decline from literacy increase, energy growth, and their interaction, based on the first three terms of the equation. The portion of infant mortality unexplained by changes in literacy and energy is constant at about 30 deaths per 1000 live births in each energy phase. This portion is more than half (56 per-

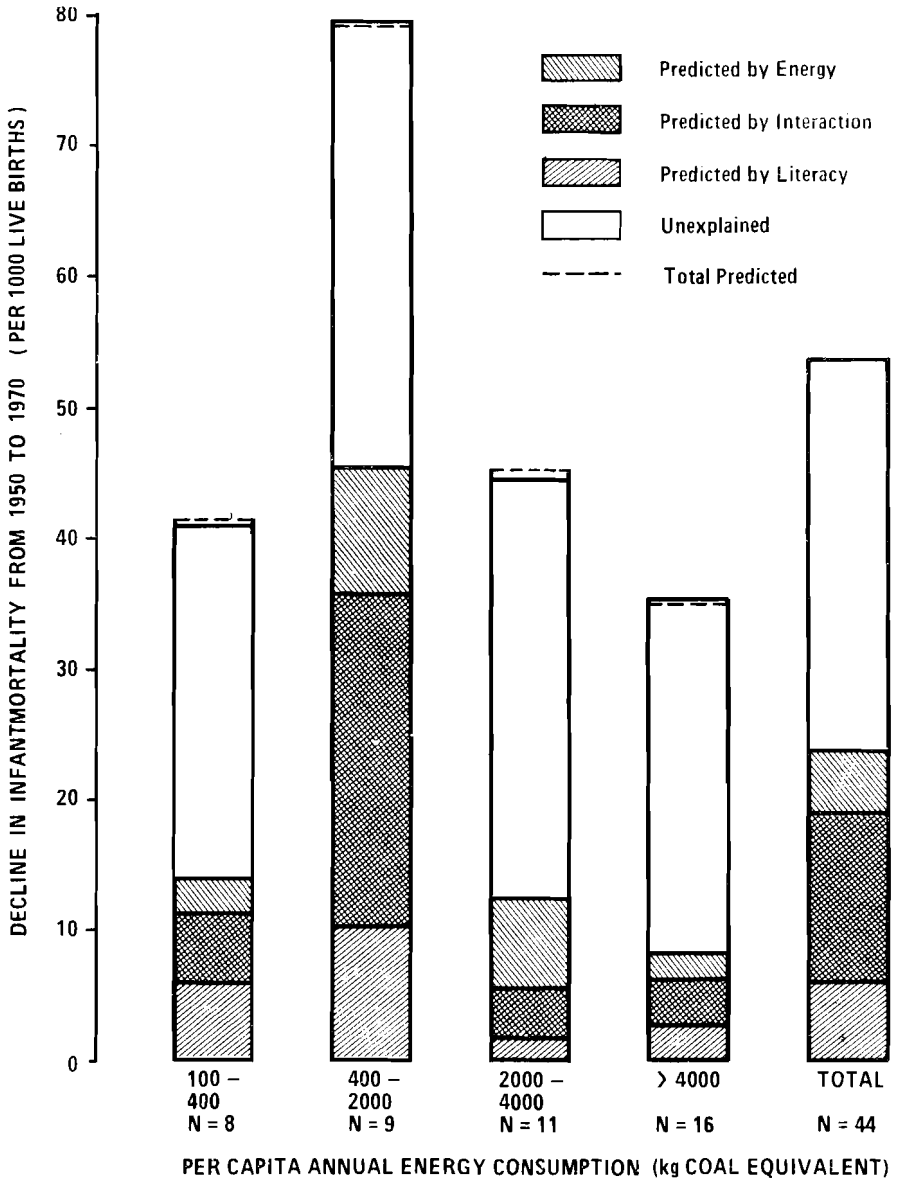

Figure 5. Decline in infant mortality, 1950 to 1970, as predicted by increased energy consumption, increased literacy, or their interaction, by level of energy consumption.

cent) of the predicted level. While these variables were able to predict declines in infant mortality with a remarkable degree of accuracy (SD reduced by 85 percent), economic development as indexed by literacy and energy consumption increases accounted for only 44 percent of the actual decline.

It is interesting to note that the figure of 44 percent, obtained solely from longitudinal analysis, is similar to the 47 to 49 percent which were arrived at by a different methodology, i.e., by applying the elasticities of literacy, energy, or total calories obtained from cross-sectional data to longitudinal changes in these variables. We conclude, with some confidence, that almost half of the worldwide decline in infant mortality is associated with increases in economic development. Our analysis does not permit us to determine whether the remainder is due to the increasing diffusion of knowledge, or the dividend from practices or programs begun before 1950, or other unknown factors.

SUMMARY AND DISCUSSION

Risk of infant death is strongly related to level of economic development. Children born under the least favorable circumstances have a 20-fold greater risk of death than those born in the most favorable circumstances. Indeed, infant mortality itself is sometimes used as a measure of economic development. The purpose of this study was to examine, from available data, those variables which are associated with economic development, and, if possible, to make some judgement about the contribution of each variable to declining infant mortality.

We were acutely aware from the outset of the limitations of our data. It is likely to be true that data collected from developing countries, where resources are limited, will be less complete than those from developed countries. International data collection is also lacking in information on factors that are known to strongly influence the outcome of pregnancy and survival of the infant, particularly those related to the personal characteristics of the mother, e.g., her age, height, marital status, and smoking habits. It would clearly also be useful to have information regarding stillbirths, specific age of death, whether the birth had medical attendance, and cause of death. None of this is available for large numbers of countries.

There are certain advantages in the use of national data. We avoid the problem of sampling errors: our sample was the universe, and we were interested in all children. We also had available aggregated data on literacy, sanitation, religion, and other variables that often cannot be studied in smaller, more homogenous populations. A number of useful observations emerged.

The relationship between energy consumption, used as an index of economic development, and infant mortality is not lin-

ear. There is no clear relationship of the two quantities below 100 kgce or above 4000 kgce. We chose to fit the data to a logistic curve, as seen in Figure 1. Many biological phenomena, including growth curves, follow such a pattern. Whatever factors are operating to reduce infant mortality apparently have a lower threshold and an upper optimal level beyond which no further benefits seem to accrue.

The relationship between energy consumption and infant mortality appears to be changing over time (Figure 1). The effect of energy--and presumably of all other factors with which energy is associated, i.e., nutritional calories, medical services, economic goods and services--is declining with time. Our own data suggest that less than half of the worldwide decline in infant mortality between 1950 and 1970 is associated with economic development.

Education

Of all the variables tested, literacy was consistently the most strongly associated with a decline in infant mortality. Correlations were high in cross-sectional data for 1950, 1970, and the worldwide sample of 1975. Increasing literacy rates were also strongly (negatively) correlated with infant mortality over the 20-year longitudinal study period. Literacy improvement alone could "account" for 48 percent of the worldwide decline in infant mortality, although it is likely that, to some extent, it also serves as a proxy for other factors. Although Cipolla [17] and others [18] have written extensively on the role of education and economic development, there is little critical work on the relationship between education and infant mortality in international comparisons.

There are a number of plausible explanations of this relationship. Those who are educated are less likely to depend upon folk medicine, which may be not only ineffective but harmful. Bomgaars [19] reports that undernourished babies in Nepal, whose condition is thought to be due to the spell cast by pregnant women, are traditionally treated with warm baths, in spite of the fact that easily available native foods are highly effective in treating the condition. Literate persons are also able to avail themselves of modern techniques of child care.

Another intriguing explanation is suggested by the work of Inkeles and Smith [20]. They have identified a fairly constant set of personal characteristics, which they describe as those of a modern man, found in several developing countries. Their description of such a person is as follows: "He is an informed participant citizen; he is highly independent and autonomous in his relations to traditional sources of influence, especially when he is making basic decisions about how to conduct his personal affairs; and he is ready for new experiences and ideas, that is, he is relatively open minded and cognitively flexible".

They found that the most important experience in producing modernism is eduation. The significance of literacy may well be that it presents a proxy for the set of values and attitudes towards life called modern, which may imply a heightened concern for health and survival of the infant. Obviously, mechanisms underlying this relationship deserve exploration. One useful area may be the matter of increased handling and fondling of the child, shown in so many animal and human studies to have a benefical effect on development.

Nutrition

Whereas the relation of maternal nutrition to pregnancy outcome remains unsettled [21,22], there can be little question that malnutrition plays a crucial role in infant mortality, particularly in developing countries. Often, the role of malnutrition is concealed in vital statistics data by infections such as diarrheas and pneunomias, which are far more common and severe in the malnourished child. Similarly, the resultant infection is likely to aggravate the level of malnutrition [23]. Although dietary protein requirements are given careful attention by pediatricians, our data show total calories to be a more significant measure of nutritional adequacy in national food supplies as measured by infant mortality rates than are protein calories. Latham [24] points out that there has been an overemphasis on the importance of dietary protein, since, when the staple food is cereal, protein deficiency rarely occurs unless there is also a caloric deficiency.

Our analyses of nutritional data show high correlations with reductions in infant mortality. Both total calories and protein calories derived from animal protein maintain their strong correlation in longitudinal as well as in cross-sectional data. We are reluctant to attribute much of the infant mortality decline to this factor since we have so little evidence that infant nutrition relates directly to aggregated national data. Furthermore, we have longitudinal nutritional data on only a small sample of 22 countries.

On the other hand, examination of national nutritional data can be justified for the following reasons. Although there are very few survey data on distribution of nutritional factors by age, or by economic status within nations, the data that do exist suggest that, if there is not enough food for the whole family, the working adults tend to take the largest share for themselves [25]. Surveys carried out in Nigeria, Kenya, and Guatemala found that children's intake of nutrients is not proportional to the nutrient supply available in the household. Children may also lose their appetite, and the efficiency with which their bodies are able to utilize nutrients is reduced due to infections. Or they may not be able to eat enough of the monotonous bulky staple food provided at the one or two major meals served during the day. One attempt to adjust estimates of malnutrition for maldistribution of foodstuffs within coun-

tries has produced a much larger estimate of malnutrition than would be derived from maldistribution of food among nations [26].

Critical to an evaluation of infant nutrition is an estimate of weaning age. The frequency of malnutrition and infectious disease and the consequent risk of death increase precipitously following weaning. Unfortunately, earlier weaning is apparently increasing throughout the world. Participation of mothers in the work force, urbanization, and limitation of more affluent classes seem to underlie this phenomenon. In wealthier communities, families may substitute cow's milk and an otherwise adequate diet, whereas poorer families cannot afford to do so. For example, Reutlinger and Selowsky [26] calculate that the unskilled working mother of a newborn infant in Calcutta must spend over 50 percent of her income on cow's milk if she is to replace the nutritional value of her own milk. We conclude that, although the demonstrated relationship between national food supplies and infant mortality is strong, there are hidden intervening variables that are operating.

Medical Care

The correlation coefficients of the two medical variables (population per hospital bed and per doctor) to infant mortality were both high, $r = 0.86$ and 0.89, respectively. Statistical performance of these variables was otherwise weak. For example, the correlations within phases were nonsignificant or in the wrong direction in 7 out of 10 estimates. Furthermore, the longitudinal analysis demonstrated nonsignificant correlations between reductions in populations per bed or per doctor and infant mortality.

There are a number of reasons for scepticism regarding the effectiveness of therapeutic services in reducing infant mortality rates in the developing countries:

- Examination of longitudinal trends of infant mortality in developed countries shows a steady decline beginning in the early part of this century. Since there was little in the way of specific therapy available in earlier decades, it is unlikely that therapeutic health care could have effectively contributed to observed declines [27].
- Since much of infant mortality beyond the immediate neonatal period is environmental in origin, therapeutic interventions are not likely to be effective. For example, 80 percent of children between 7 months and 2 years of age admitted to a Johannesburg hospital were significantly malnourished [28]. A follow-up of children hospitalized in Iran revealed that a third had subsequently died [29]. Furthermore, few of those who survived had significantly improved their weight relative to their age.

- Examination of specific causes of death among infants reveals that in the neonatal period (first month) there are a variety of vague, ill-defined conditions and congenital malformations. Only rarely are there recognizable defects for which curative intervention is available. The very slow decline in infant mortality rates in developed countries is a reflection of this. Beyond the neonatal period, infections such as diarrheas and pneumonias are complications of other underlying pathology, frequently malnutrition. Studies have shown that the frequency of infectious diseases causing mortality among children show a significant decline when nutritional supplements are added [30]. When both medical care and nutritional supplements were provided in an experiment in India, the nutritional supplements had the major impact [31].

On the other hand, several investigators have found significant effects of adequate obstetric and pediatric care in the developed countries where the major problem of nutrition has been overcome. For example, it is estimated that the infant mortality of 21.9 per 1000 live births in New York City (1968) could have been reduced to 14.7--a 33-percent reduction--had all pregnant women received adequate care [32]. Such studies, even when controlled for socio-economic and medical variables, demonstrate an effect of medical care in reducing infant mortality risk. In another New York study, it was concluded that 75 percent of the decline in infant mortality in the past decade was due to spontaneous reduction in the frequency of high-risk, low-birth-weight children, and that only 25 percent could be attributed to medical care [33]. Thus, while in the developing countries medical care appears to be outweighed in importance by nutrition, it may play some role in the more developed countries where nutrition is no longer a problem.

Urbanization

Urbanization appears to be one of the unalterable features of economic development. The pattern of urbanization accompanying development has recently been described by Rogers [34]:

- During the initial period of city formation the rate of urban growth is exceeded by the rate of rural growth.
- At some point in the history of the nation or region a reversal occurs, and the urban growth rate outstrips the rate of increase of the rural population, thereby imitating the growth of urbanization.
- Eventually a "turning point" is reached as the proportion of the population that is urban exceeds 50 percent for the first time.
- With the continuous decline in agriculture's share of the total labor force, the rural population ceases to grow and begins to decline in number.

- In the late states of industrialization, a decentralization occurs, producing a more dispersed population.

Although urban-rural mortality rates have often differed, there has been no consistent pattern. In Scandinavia, urban infant death rates were historically at least 50 percent greater than rural infant death rates. That discrepancy has gradually disappeared as urban death rates fell more rapidly than did rural rates, so that by 1960 they were identical [35]. In the developing countries today, infant mortality appears to be lower in cities than in rural areas. This has been shown in South America, Africa, and Mexico [36]. Conflicting data on the effect of urbanization on infant mortality could well be the result of a number of factors influencing infant mortality in different directions: crowding, employment of women, availability of medical care, and differences in weaning practices.

Role of Economic Development

Equation (1), which incorporates information on both secular and economic factors, allows us to predict 1970 infant mortality levels with a high degree of accuracy (Figure 5). Almost half of the decline can be attributed to economic development, as reflected by increased energy consumption, increased literacy, and their interaction. The remainder is unexplained. These findings can be compared with those of Preston [37] who studied the effect of economic development as measured by GNP on longevity from birth, a statistic highly correlated with infant mortality. He estimated that 16 percent of the improvement in health from 1938 to 1963 could be attributed to economic factors per se.

As indicated by the relationship implied in Equation (1) and graphically shown in Figure 4, improvements in literacy and/or economic development as measured by energy consumption will to a certain extent substitute for each other. A few extreme examples illustrate the point. Over the interval 1950-1970, Oatar increased its per capita energy consumption from 50 to almost 10,000 kgce, a 200-fold increase. Literacy rates increased from an estimated 2.5 percent to 12.5 percent in 1970. Substituting in Equation (1), the predicted declines in infant mortality were 3.8, 22.6, and 29.7 from literacy increase, energy increase, and their interaction, respectively; a total of 56.1 per 1000 live births. The observed decline was, in fact, an estimated 62 (from 200 to 138). At the other extreme are the 8 countries in Phase IIa (Figure 5) for whom improvement in literacy contributed more to reduction of infant mortality than did economic development, but still not as much as did other unexplained factors.

In conclusion, we have identified two factors that have had a powerful effect on reducing infant mortality rates throughout the world. One of these is closely related to economic development as measured by an index combining national energy con-

sumption and literacy rates. Of the individual factors contributing to this effect, education is the most powerful variable identified. The other factor, unrelated to economic development and operating universally, accounts for at least 50 percent of the decline in infant death rates. Plausible conjectures explaining this phenomenon are a natural decrease in the virulence of infectious disease, an increase in human resistance, or both.

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